Cool Roofs:
From Cool Cities to a Cooler World

Haagen-Smit Symposium
June 3, 2009

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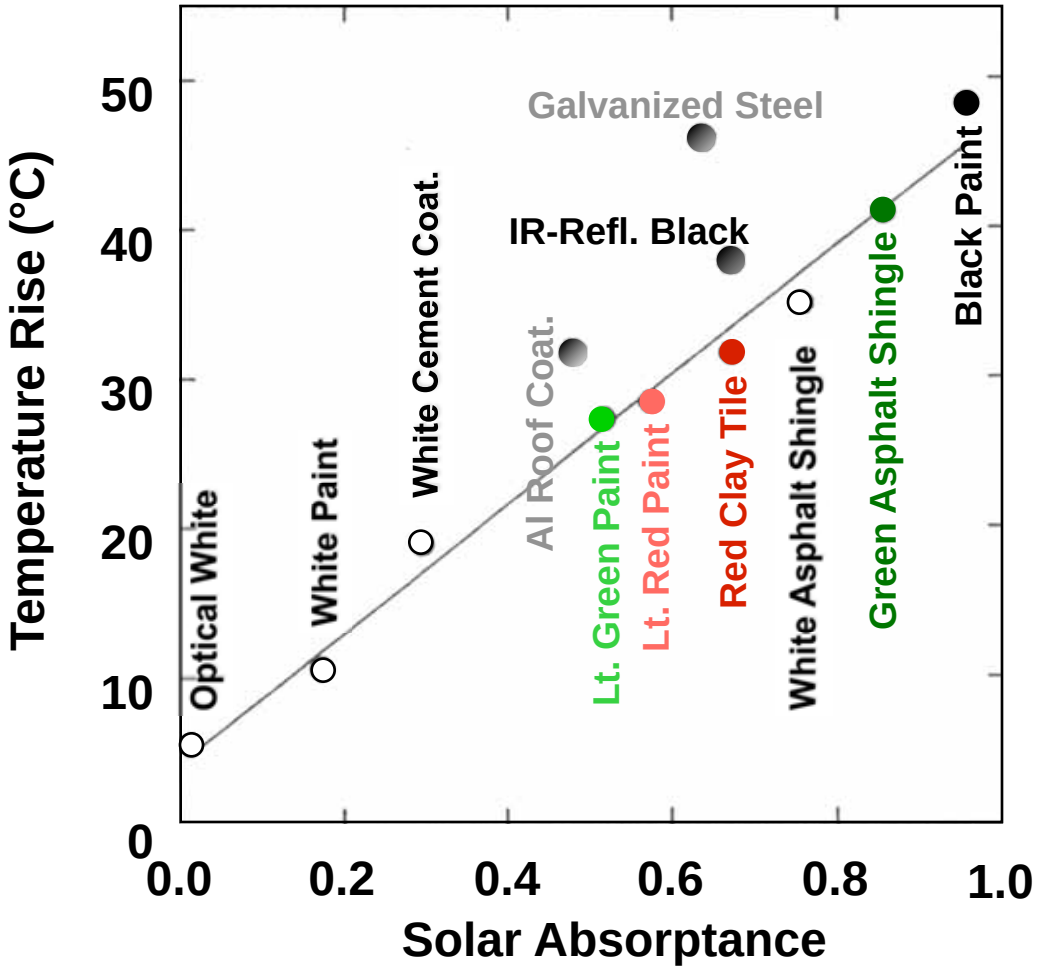
Santorini, Greece

White is ‘cool’ in Bermuda

and in Hyderabad, India

…and widely in the State of Gujarat, India

Reflective roofs have lower temperatures in sunlight



To be published in Climatic Change, May-June 2009

Global Cooling: Increasing World-wide Urban Albedos to Offset CO_2

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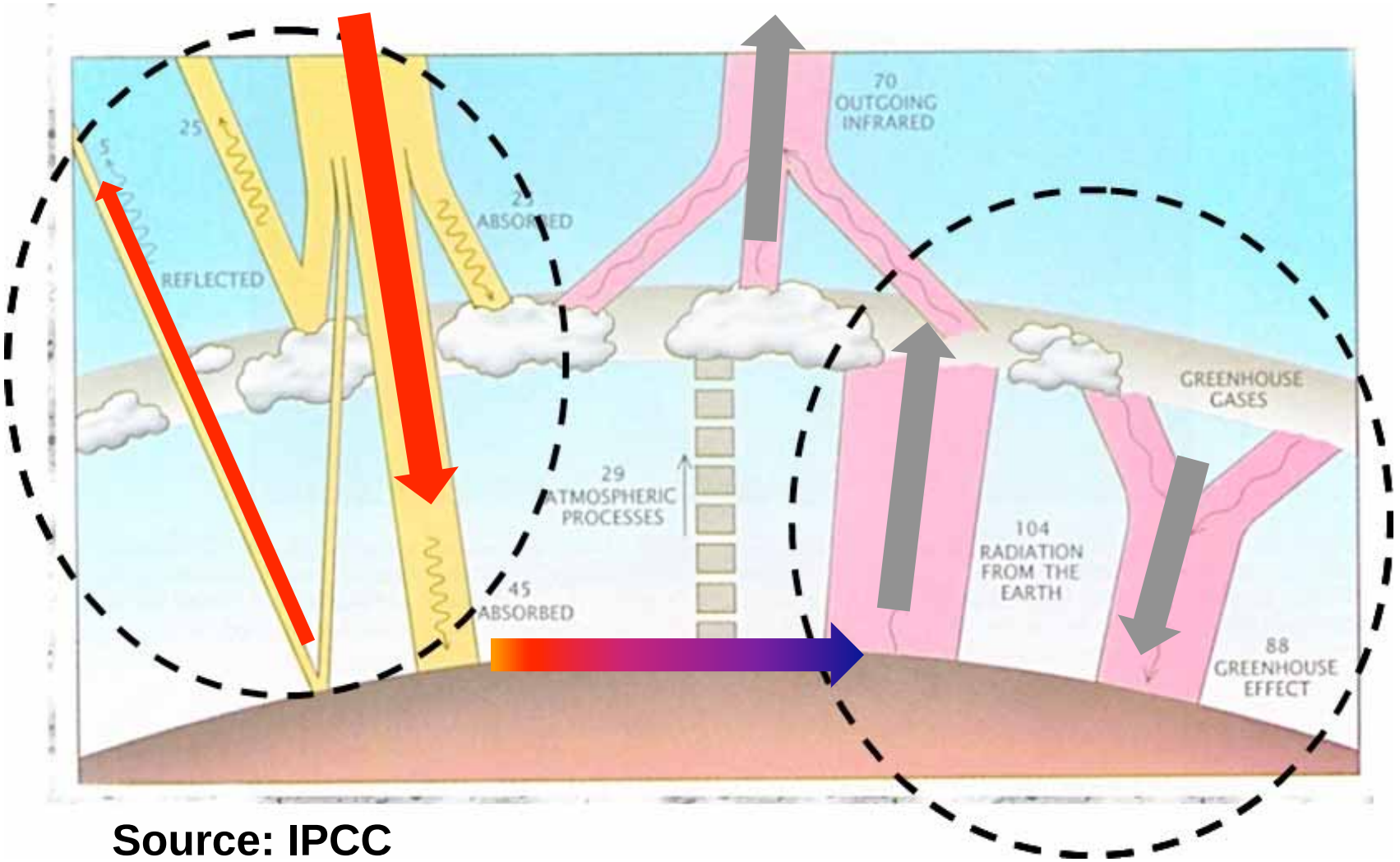
A first step in geo-engineering which saves money and has known positive environmental consequences

Solar Reflective Surfaces Also Cool the Globe



Source: IPCC

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Methodology

- Changing albedo of urban surfaces and changing atmospheric CO_2 concentrations both result in a change in radiative forcing.
- Comparing these two radiative forcings relates changes in solar reflectance of urban surfaces to the changes in atmospheric CO_2 content.

Caveats

- Time dependence of physical effects (e.g., sequestration in land or ocean) and economics are ignored.
- We account for the effect of multiple scattering and absorption of radiation within the atmosphere.
- Calculations are performed for the entire globe

Radiation Forcing of $2XCO_2$

- Hansen et al (2005) estimate a $2XCO_2$ radiation forcing (RF) on the top of the atmosphere of 3.95 ± 0.11 W/m^2, yielding a RF of 0.93 ± 0.03 kW/tonne of atmospheric CO_2
- IPPC [based on Myhre (1998) formula] estimate a RF of 3.71 W/m^2, yielding a RF of 0.88-0.91 kW/tonne of atmospheric CO_2
- Matthews and Caldeira (2008) found a 0.175 K temperature increase for every 100 GtC emitted, yielding a 0.47 kW/tonne of atmospheric CO_2
- We use a RF of 0.91 kW/tonne of atmospheric CO_2

Radiation Forcing of Cool Surfaces

- Hansen et al. (1997) estimate a RF of -3.70 Wm^{-2} for increasing the albedo of 'Tropicana' by 0.2. We estimate that Tropicana is 22% of the land area or about $1/16^{th}$ of the global surface. For the reflected surfaces, the RF per 0.01 increase in albedo is -2.92 W per m^2 of Tropicana land.
- Using Kiehl and Trenberth (1997) and Hatzianastassiou et al. (2005), we calculate a RF of -1.27 W/m^2 per 0.01 increase in albedo of modified surfaces.
- Note that our calculations apply for the average cloud cover over the earth; we estimate higher RF for CA

CO_2-Equalence of Reflective Surfaces

- RF of increasing atmospheric CO_2 = 0.91 kW/tonne
  = 0.91 W/kg
- RF of increasing solar reflectance of a surface by 0.01
  = -1.27 W/m^2
- Atmospheric CO_2-equalence of increasing solar reflectance of a surface by 0.01 = -1.27 [W/m^2]/ 0.91 [W/kg]
  = -1.40 kg/m^2
- IPCC (2007) estimates that only 55% of the emitted CO_2 stays in the atmosphere
- Emitted CO_2-equalence of increasing solar reflectance of a surface by 0.01 = -1.40 [kg/m^2]/0.55 = -2.5 kg CO_2 per m^2

CO_2 Offset of Cool Roofs and Cool Pavements

- Δ albedo for aged white roofs = 0.40
- Emitted CO_2 offset for white roofs
  = [0.40/0.01]*[-2.5 kg CO_2 /m^2] = -100 kg CO_2/m^2
- It takes about 10 m^2 of roof with albedo increase of 0.40 to offset 1 T CO_2 emitted
- Δ albedo for typical residential and non-residential cool roofs = 0.25
- Emitted CO_2 offset for cool roofs
  = [0.25/0.01]*[-2.5 kg CO_2 /m^2] = -63 kg CO_2/m^2
- Δ albedo for cool pavement = 0.15
- Emitted CO_2 offset for cool pavements = -38 kg CO_2/m^2

Dense Urban Areas are 1% of Land

- Area of the Earth = 508×10^{12} m^2
- Land Area (29%) = 147×10^{12} m^2 [3]
- Area of the 100 largest cities = 0.38×10^{12} m^2
  = 0.26% of Land Area for 670 M people
- Assuming 3B live in urban area, urban areas
  = [3000/670] x 0.26% = 1.2% of land
- But smaller cities have lower population density,
  hence, urban areas = 2% of land = 3×10^{12} m^2 [4]
- Dense, developed urban areas only 1% of land
  = 1.5×10^{12} m^2 [5]

CO_2 Equivalency of Cool Roofs and Pavements

- Typical urban area is 25% roof and 35% paved surfaces
- Roof area = $0.25*1.5x10^{12}$ m^2 = $3.8x10^{11}$ m^2
- Emitted CO_2 offset for cool roofs
  = 63 kg CO_2 /m^2 * $3.8x10^{11}$ m^2 = 24 GT CO_2

- Paved area = $0.35 *1.5x10^{12}$ m^2 = $5.3x10^{11}$ m^2
- Emitted CO_2 offset for cool pavements
  = 38 kg CO_2 /m^2 *$5.3x10^{11}$ m^2 = 20 GT CO_2
- Total emitted CO2 offset for cool roofs and cool pavements = 44 GT CO_2

CO_2 Equivalency of Cool Roofs and Pavements (cntd.)

- 44 GT CO_2 is over one year of the world 2025 emission of 37 GT CO_2
- At a growth rate of 1.5% in the world's CO_2 -equivalent emission rate, 44 GT CO_2 would offset the effect of the growth in CO_2-equivalent emissions for 11 years

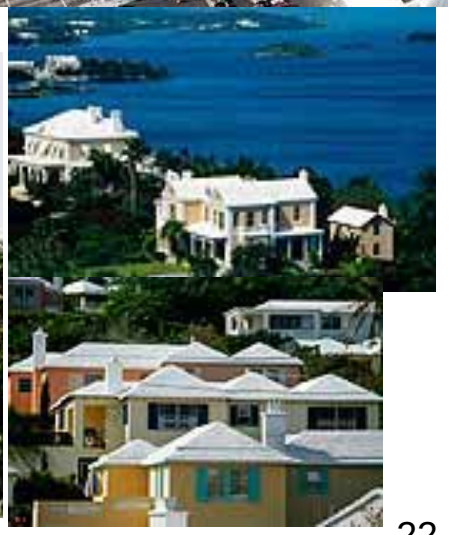
CO_2 Equivalency of Cool Roofs World-wide (Tropics + Temperate)

- Cool roofs alone could offset a total of
  24 billion tons (Gt) CO_2 = world emissions this year !!!!
- Worth > **€240 billion** (pre-recession was €600B)
- To convert 24 Gt CO_2 one-time into a rate:
  - Assume 20 year roof service life, thus 1.2 Gt CO_2/year
  - Average world car emits 4 t CO_2/year

equivalent to **300 million cars**
off the road for **20 years**

(600 million passenger cars in the world today)

100m^2(~1000 ft^2) of a white roof, replacing a dark roof, offset the emission of 10 tonnes of CO_2



How to Relate to 10 Tons of CO_2

- First – This is **10 tons ONCE**, not 10 tons/year;
- But familiar measures are usually in terms of **tons/year**;
- So we will look at how many **years of emissions** 10 tons will offset

	Tons CO_2/Yr	**Years Equivalent to 10 Tons**
Average US House Emits	10	1
Average US Car Emits	5	2
Average Global Car Emits	4	2.5
Average CFL **Saves**	.05=1/20	200

Effect of Solar Reflective Roofs and Pavements in Cooling the Globe

(Source: Akbari, Menon, Rosenfeld. *Climatic Change*, 2009)

	Δ Solar Reflectivity	CO_2 Offset by 100 m^2	CO_2 Offset Globally
White Roof	0.40	10 tons**	
Average Roof *	0.25	6.3 tons	24 Gt ***
Cool Pavement	0.15	4 tons	20 Gt
Total Potential			44 Gt
Value of 44 Gt CO_2 at \$25/t ~ \$1 Trillion			

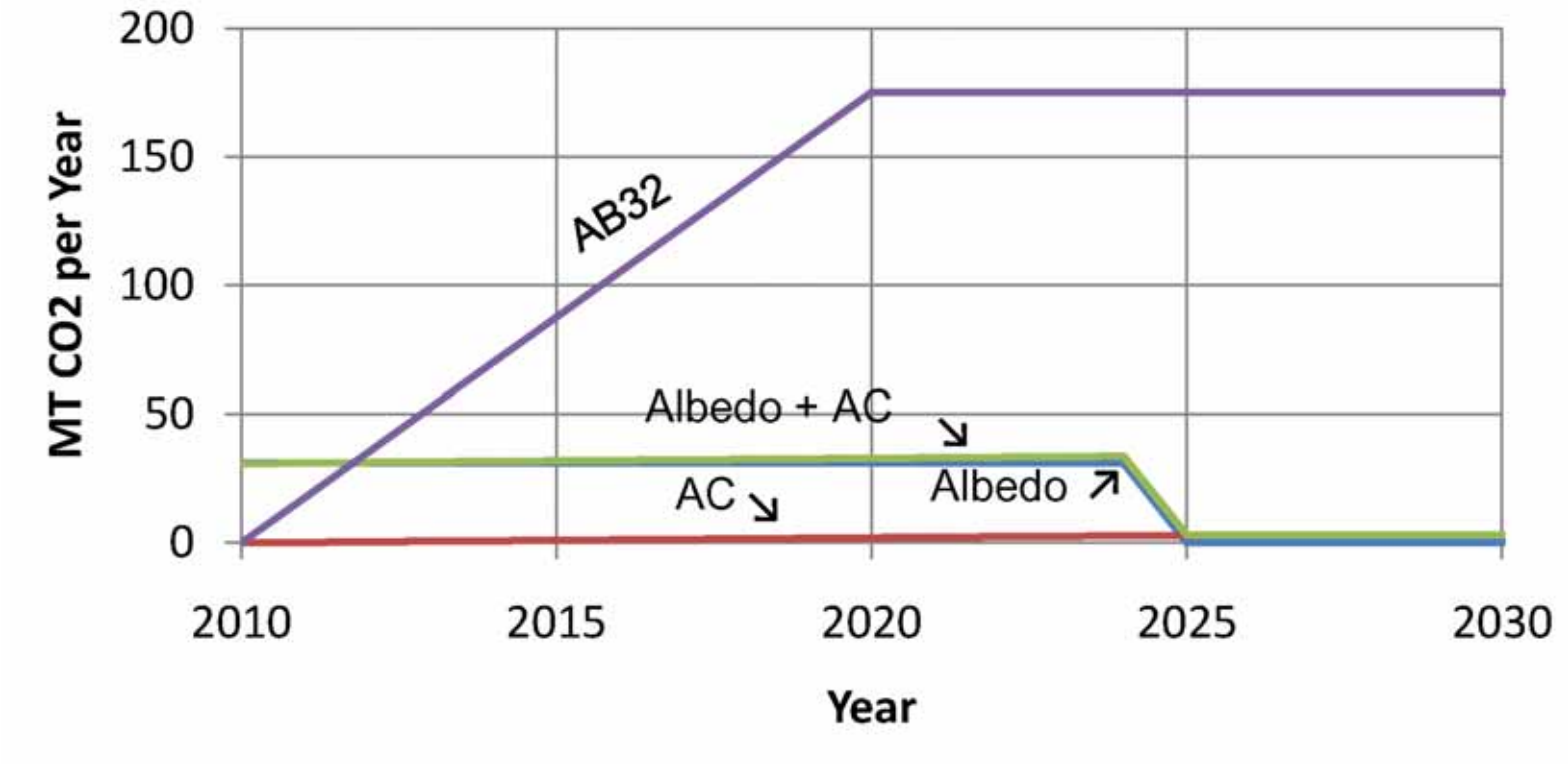
***White Roof will be "diluted" by cool colored roofs of lower reflectivity, and roofs that can not be changed, because they are long-lived tile, or perhaps they are already white.**

****Compare 10 tons with a family car, which emits ~4 tons/year.**

***** **24 Gt CO2 Offsets Global CO2 emissions in 2009**

•**Comparison of CO2 offset directly by albedo vs. CO2 reduced by AB 32**

•**Albedo reduction based on a plausible15-year program for white and cool roofs (Title 24 for new buildings and major retrofits) and a yet to be developed program for cool pavements**



Cool Roof Technologies

Old

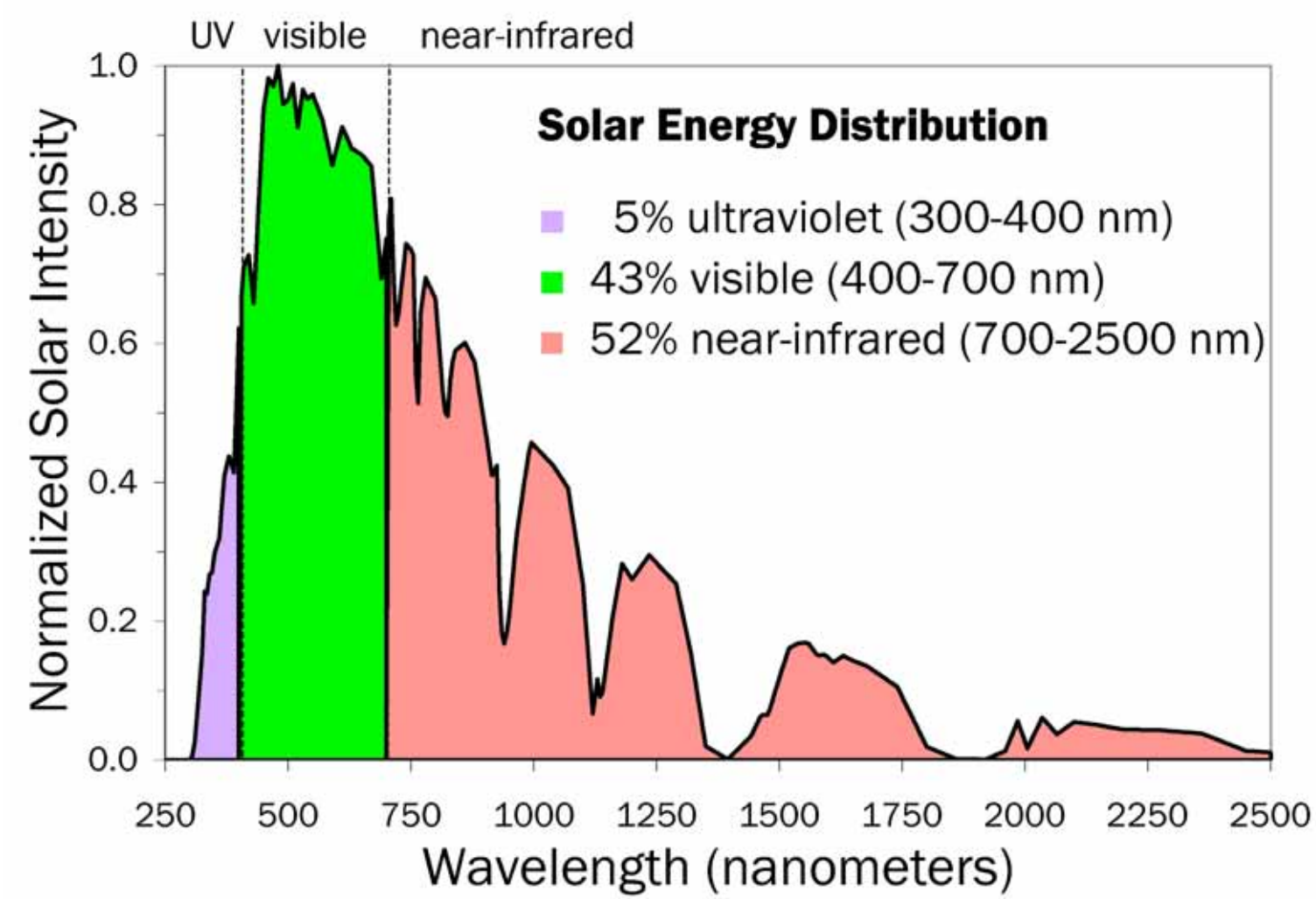
flat, white

pitched, white

New

pitched, cool & colored

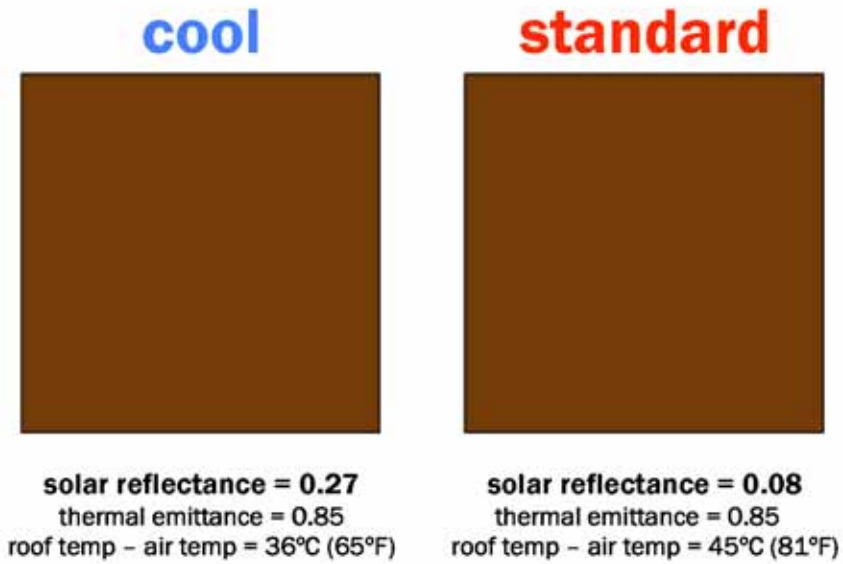
Cool Colors Reflect Invisible Near-Infrared Sunlight

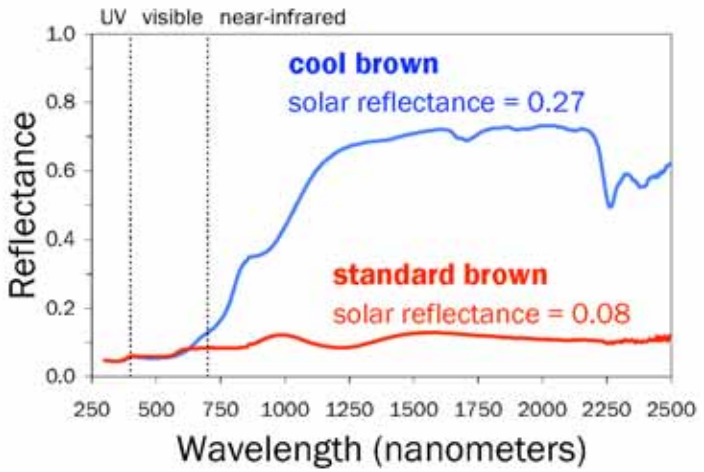


Cool and Standard Brown Metal Roofing Panels

- Solar reflectance ~ 0.2 higher
- Afternoon surface temperature ~ 10ºC lower

Courtesy BASF Coatings





Cool is cool: From cool color roofs to cool color cars and jackets

- Toyota experiment (surface temperature 10K cooler)
- Ford is also working on the technology

Courtesy: BMW (http://www.ips-innovations.com/solar_reflective_clothing.htm)

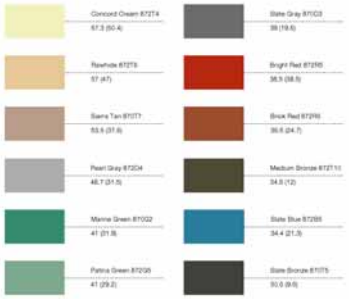
Many cool colors to choose

cool concrete tile R ≥0.40	R=0.41 *black*	R=0.44 *blue*	R=0.44 *gray*	R=0.48 *terracotta*	R=0.46 *green*	R=0.41 *chocolate*
standard concrete tile (same color)	R=0.04	R=0.18	R=0.21	R=0.33	R=0.17	R=0.12
solar reflectance gain =	**+0.37**	**+0.26**	**+0.23**	**+0.15**	**+0.29**	**+0.29**

Courtesy American Rooftile Coatings

cool clay tile R ≥0.40

Courtesy MCA Clay Tile



cool metal R ≥0.30

Courtesy BASF Industrial Coatings

cool fiberglass asphalt shingle R ≥0.25

Courtesy Elk Corporation

Pavements can also be cool

Concrete	(a) Unexposed	(b) Weathered	(c) Weathered, wetted	(d) Soiled	(e) Abraded	(f) Formed
C1:S1:R2 gray cement/ riverbed sand/ granite rock	ρ=0.44	ρ=0.34	ρ=0.14	ρ=0.43	ρ=0.24	ρ=0.25